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LATERAL RESISTANCE OF LOG TIMBER WALLS SUBJECTED TO HORIZONTAL LOADS

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ABSTRACT: The present works intends to represent a further step in the knowledge of timber log-houses through an experimental approach, from which only few information is available. The main part of the experimental work is based on in-plane static tests conducted on timber log walls with distinct transversal stiffness, two vertical compression levels and two values of slenderness. Monotonic and cyclic tests were performed according to EN 12512:2001. The formers were performed to define the elastic slip values and assessment of the failure mechanisms while the lasts allowed evaluating impairment of strength, to measure the ductility and to quantify the energy dissipation. In a first step research, an extensive characterization of the timber logs was made. The connection between the first timber log and the basement was also evaluated.

KEYWORDS: Log-house, characterization, logs, walls, cyclic tests.

1 INTRODUCTION

Timber log constructions are popular in many forest regions of the world, especially in North America and Scandinavia. Their use in earthquake zones is also common, despite design criteria for lateral resistance of log shear walls, have not been given reasonably yet [1].

Timber log constructions are formed by stacking horizontal layers of logs, where log cross-section, grade, and construction details vary among manufacturers.

Under vertical loads walls are mainly subjected to low compression perpendicular to the grain. However, wall height changes dimensions as logs lose and absorb moisture while settlements due to logs creep deformation are expected.

Lateral loads in log shear walls are generally transferred through: (1) interlocks between logs, (2) wood or steel dowels, (3) vertical through bolts and anchor-bolts, (4) frictions between logs due to vertical loads.

As mentioned, some variations to the system and resisting elements can be found. For example, Figure 1 represents the lateral resisting elements of log shear walls produced by Rusticasa, a Portuguese manufacturer that marks since 1978.

Existing design standards for log constructions only count wood or steel dowels and vertical through bolts [2]. This is mainly because the interlocks are too variable to be given definite allowable resistance and it is indefinite how to evaluate the frictional resistance due to vertical loads whose effective values may be periodically dropped by the vertical components of earthquake forces. Actual contributions of counted or uncounted resisting elements above, however, are mostly unclear [1].

The University of Minho was contacted to perform a series of experimental and numerical studies to support the European Technical Approval of the timber log constructions produced by Rusticasa. This paper presents some of the most important studies carried out according to ETAG-012 [3].

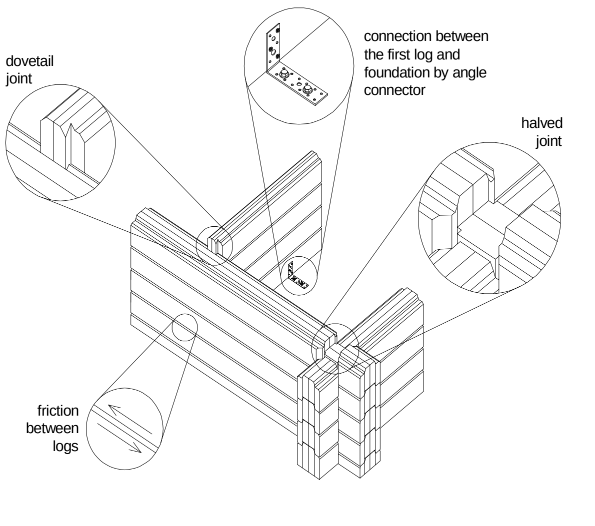

Figure 1: *Lateral resisting elements of log shear walls*

2 TIMBER LOGS

The basic component of this system produced by Rusticasa, are logs obtained from lamellas (40 mm) glued face to face, representing an example of vertical glulam, as defined in EN 386:2001 [4]. Three

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thicknesses are available for the logs: 80 mm (2 lamellas), 120 mm (3 lamellas) and 160 mm (4 lamellas). Notches are made in the up and bottom surfaces of the logs. Those notches increase the interlock and the friction between horizontal layers of logs. Figure 2 presents the logs cross-sections available on the Rusticasa system.

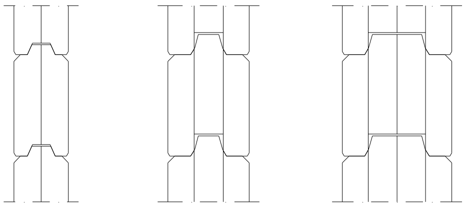


Figure 2: *Available logs cross-sections. (a) 80 mm; (b) 120 mm; (c) 160 mm.*

Lamellas are made of Scots pine (*Pinus sylvestris* L.), bought to the Scandinavian supplier with the minimum requirement to belong to Quality Class VI (or Class C under the new designation), according to [5]. In other words, lamellas are bought based on a visual classification for non-structural applications.

Using NP EN 1194:1999 [6] it is possible to predict the global behaviour (log) based on the mechanical properties of the lamellas. However, in this case, no references values are known for the lamellas. Therefore, it was decided to perform an experimental analysis of the logs under compression and bending.

Adopting the EN 408:2003 [7] requirements, the following tests were carried out at the Structures Laboratory of University of Minho (LEST): a) bending tests with three different cross-sections: 80×150 mm^2 (2 lamellas), 120×150 mm^2 (3 lamellas) and 160×150 mm^2 (4 lamellas); b) compression parallel to grain using three specimens: 45×270×80 mm^3 (1 lamella), 120×480×80 mm^3 (3 lamellas) and 160×480×80 mm^3 (4 lamellas); and c) compression perpendicular to grain using three types of specimens: 45×90×70 mm^3 (1 lamella), 120×150×156 mm^3 (3 lamellas) and 160×150×208 mm^3 (4 lamellas). Tables 1, 2 and 3 summarized the mean values obtained based on 8 results for each type of test. More details of this experimental evaluation can be found in [8].

Table 1: *Mean values obtained for the bending strength (f_m) and modulus of elasticity in bending (MoE)*

Cross-section (mm^2)	f_m (MPa)	MoE (MPa)
80×150	37	11400
120×150	43	12000
160×150	44	12300

As general conclusion it is possible to point out that the presence of a greater number of glued surfaces ensures a more global behaviour of the cross-section. It is also important to point out that the failures observed were influenced by the presence of nodes and number of glued surfaces.

Table 2: *Mean values obtained for the strength ($f_{c,0}$) and modulus of elasticity ($E_{c,0}$) under compression parallel to the grain*

Specimen (mm^3)	$f_{c,0}$ (MPa)	$E_{c,0}$ (MPa)
45×270×80	37	10900
120×480×80	33	11900
160×480×80	33	11000

Table 3: *Mean values obtained for the strength ($f_{c,90}$) and modulus of elasticity ($E_{c,90}$) under compression perpendicular to the grain*

Specimen (mm^3)	$f_{c,90}$ (MPa)	$E_{c,90}$ (MPa)
45×90×70	2.4	309
120×150×156	3.2	315
160×150×208	3.2	380

3 CONNECTION BETWEEN THE FIRST LOG AND FOUNDATION

In timber log constructions, connections between the first log and the foundation are normally achieved through anchor bolts using holes, spaced 120 cm on average, using oversized to facilitate construction. Anchor bolts lose tightness as the log shrinks due to drying and anchor bolts nuts may be inaccessible so it they cannot be tightened later in the life of the structure [9]. In the Rusticasa system, the connection between the first log and the foundation is made using an angle connector (BMF 40314), every 150 cm, with three screws (5x50 mm) in the timber side and two metal anchors (M8) fixed to the concrete, Figure 3.

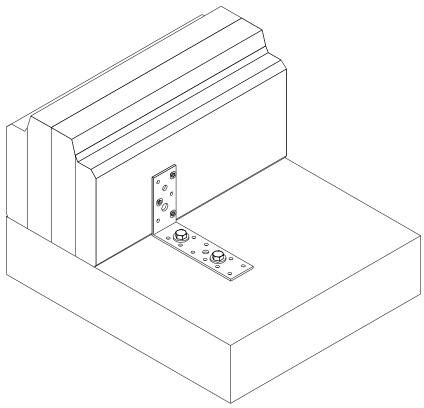


Figure 3: *Connection between the first log and the foundation used by the Rusticasa system*

Applying the expressions of Eurocode 5 [10] section 8, a value of 3,57 kN is obtained for the resistance of the connections for both directions (parallel and perpendicular to the log axis).

Apart the numeric analyses, two types of cyclic tests were performed to evaluate the behaviour of this connection. Using three specimens for each type, the connection was submitted in the wall plane to shear

(Figure 4a, loaded in the direction of the log axis) and to tension (Figure 4b, loaded in the direction perpendicular to the log).

a) Shear test

b) Tension test

Figure 4: *Specimens layout used for the tests of the connection between the first log and the foundation*

For both kinds of tests, a quasi static cyclic loading procedure in accordance with EN 12512:2001 [12] was assumed. For the shear tests (S) complete cycles were used (Figure 5) while half cycles (only in the tension side) were adopted in the tension tests (T) (Figure 6).

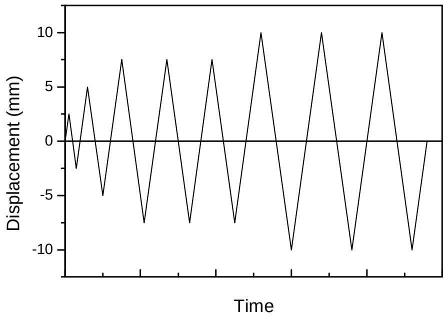


Figure 5: *Loading procedure for shear tests*

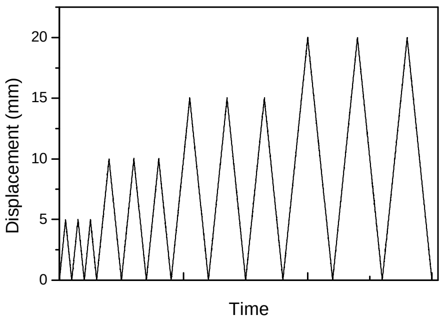


Figure 6: *Loading procedure for tensile tests*

Figure 7 presents the experimental load-displacement curves obtained in the shear tests. The first shear test was not considered because important rotation of the specimen, around the connection axis, occurred due to a misconceived test layout. After the improvement of the test layout (Figure 4a), shear tests were carried out applying pure shear to the connection, as wanted.

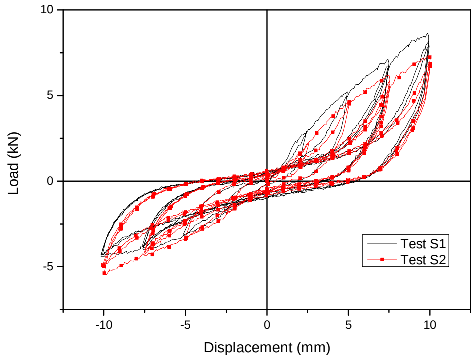


Figure 7: *Load-displacement curves obtained from shear tests (S)*

The results obtained from both tests (S1 and S2) show a good agreement. They demonstrate a good ductility and an important capacity of those connections to dissipate energy under shear. The response is not symmetric. The load increases with the amplitude of the cycle while the stiffness decreases. As characteristic of timber joints, considerable pinching is observed. The impairment of the strength is low, under 10% in the compression side (positive) and less than 5 % in the tension side.
Table 4 summarizes the maximum load and stiffness values, per cycle, obtained from the shear tests performed.

Table 4: *Maximum load and stiffness values obtained from the shear cyclic tests (S)*

Displacement (mm)	Max. load (kN)		Stiffness (kN/m)	
	Test S1	Test S2	Test S1	Test S2
2,5	2,893	2,219	1,208	1,180
-2,5	-1,764	-1,922	0,511	0,732
5	5,222	4,627	1,248	0,894
-5	-3,220	-3,319	0,508	0,678
7,5	7,124	6,193	0,764	0,654
-7,5	-3,993	-4,34	0,400	0,540
7,5	6,678	5,777	0,491	0,507
-7,5	-3,884	-4,171	0,318	0,419
7,5	6,589	5,539	0,495	0,438
-7,5	-3,825	-4,033	0,300	0,385
10	8,640	7,322	0,722	0,559
-10	-4,389	-5,469	0,303	0,400
10	8,184	6,876	0,533	0,467
-10	-4,29	-4,964	0,271	0,315
10	7,917	6,728	0,519	0,465
-10	-4,300	-4,895	0,258	0,311

Figure 8 shows the experimental load-displacement curves obtained from the three tension tests performed.

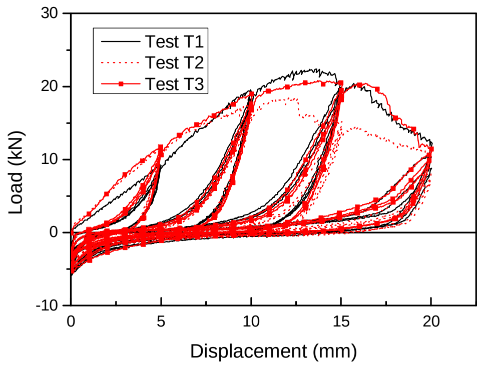


Figure 8: *Load-displacement curves obtained from tension tests (T)*

Analysing in detail the results obtained, it is possible to conclude that 15 mm of deformation, in agreement with EN 26891: 1991 [2], determines the maximum resistance of the connection. The results obtained from the three specimens are consistent, apart slight variations between the experimental values achieved. In terms of maximum load, this value has increased with the cycle amplitude until 15 mm, after which, there is a significant impairment of the strength. The same conclusions can be extended to the stiffness experimental values achieved. In particular, a major reduction of the stiffness value is measured in the last cycle amplitude (20 mm), between the first and the third cycles.
Tables 5 and 6 presents the experimental results of the maximum load and stiffness for the tension tests performed on the connections between the first log and the foundation.

Table 5: *Maximum load values obtained from the tension cyclic tests (T)*

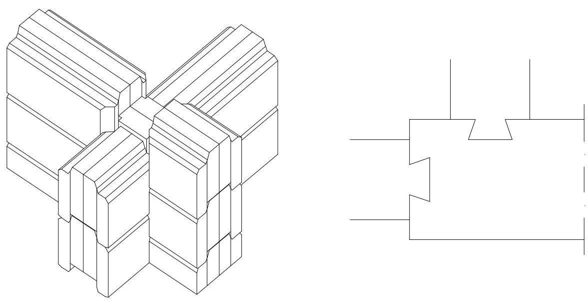
Displacement (mm)	Maximum load (kN)		
	Test T1	Test T2	Test T3
5	9,334	11,434	11,791
	9,175	10,840	11,226
	8,808	10,384	10,978
10	19,549	17,577	19,064
	19,133	16,349	17,746
	18,370	15,764	17,211
15	22,393	18,420	20,827
	19,866	14,139	19,490
	19,609	13,872	18,776
20	20,451	14,436	20,401
	10,404	8,135	10,919
	8,818	7,154	10,037

Table 6: *Stiffness values obtained from the tension cyclic tests (T)*

Displacement (mm)	Stiffness (kN/m)		
	Test T1	Test T2	Test T3
5	1,781	2,208	2,381
	1,618	1,942	1,955
	1,506	2,009	1,948
10	3,016	3,037	1,506
	2,291	2,554	2,430
	2,285	2,561	2,523
15	2,756	2,997	2,923
	1,773	1,643	1,951
	1,914	1,667	2,085
20	2,074	1,669	2,383
	0,394	0,537	0,604
	0,320	0,421	0,555

4 IN-PLANE BEHAVIOR OF LOG-TO-LOG

The in-plane behaviour of timber log walls is ensure by the friction forces developed in the notches existing in the top and bottom of the logs and by the interception between orthogonal walls.
The Rusticasa system defines as maximum distance between two consecutive interceptions: 4 meters for 80 mm thick walls, 6 meters for walls with a thickness of 120 mm and 8 meters in the case of 160 mm thick walls. Those interceptions can be of 2 types: two exterior walls (halved joint) or one exterior wall with an interior wall (dovetail joint), Figure 9.



(a) (b)

Figure 9: *Possible interceptions between orthogonal log walls. (a) Two exterior walls through halved joints; (b) one exterior wall with an interior by dovetail joints*

In accordance with Eurocode 5, friction cannot be regarded as a resistant mechanism, despite its importance in this kind of timber structural system. Therefore, the in-plane resistance of log walls is determined based on the compression perpendicular to the grain and shear stresses developed at the interceptions between walls. In fact, in the halved joints there are both compression stresses, perpendicular and parallel to the grain, but, as the second is higher, it is the former that governs the resistance. Then the resistant capacity offered by the intersection of two walls can be quantified as:

$$R_h = \min\begin{cases} f_{c,90,d} \times A_{r,comp} \\ f_{v,d} \times A_{r,shear} \times 4/3 \end{cases} \quad (1)$$

where $f_{c,90,d}$ is the design value of compressive strength perpendicular to the grain, $f_{v,d}$ is the design value for the shear strength, $A_{r,comp}$ and $A_{r,shear}$ represent, respectively, the contact area where strengths of compression perpendicular to the grain and shear can develop.

Equation (1) allows quantifying the in-plane resistance given by interceptions exterior-exterior and exterior-interior walls, despite their cross-section. The total in-plane resistance of a log wall is given by the sum of the individual resistance of each interception existing in the wall:

$$R_{h,TOTAL} = \sum_{i=1}^{n} R_{h,i} \quad (2)$$

where $R_{h,i}$ is the in-plane resistance to horizontal actions of a wall guaranteed by the interception *i*.

Tables 7 and 8 present the in-plane resistance given by an interception for different load duration and type of load combination and assuming service class 3.

Table 7: *In-plane resistance for different interceptions assuming service class 3, accidental combination and an instantaneous load (earthquake)*

Interception	$R_{h,i}$ (kN)
2 exterior walls of 160 mm	13,72
2 exterior walls of 120 mm	7,62
Int. of 80 mm with the outer wall	9,48
Int. of 120 mm with the outer wall	8,84

Table 8: *In-plane resistance for different interceptions assuming service class 3, fundamental combination and short duration load (wind)*

Interception	$R_{h,i}$ (kN)
2 exterior walls of 160 mm	8,54
2 exterior walls of 120 mm	4,74
Int. of 80 mm with the outer wall	5,90
Int. of 120 mm with the outer wall	5,50

As example, the in-plane resistance of an exterior wall of 160 mm, which intercepts 3 interior walls of 80 mm, under the wind action, is given by:

$$R_{h,TOTAL} = 8{,}54 \times 2 + 5{,}90 \times 3 = 34{,}78 kN \quad (3)$$

In order to evaluate the friction developed in the two notches that each log has along its length, an experimental campaign was performed. In a first step, a specimen composed by three logs was tested under monotonic loading under two vertical compression values. After, full-scale walls were analysed through cyclic tests under four different vertical compression values.

In the first step, the vertical compression (3,0 kN and 3,9 kN) was applied using cycles to ensure the adequate contact between logs. Then, the vertical compression was kept constant during the application of a horizontal displacement to the central log.

The vertical compression was applied at a constant rate of 12,5 N/s and the horizontal displacement was applied at a constant rate of 0,120 mm/s. Four transducers (two on each side of the specimen) were used to measure displacements: 2 for measuring the vertical displacement and 2 arranged horizontally to measure the horizontal slip between logs. The equipment consists of two servo-controlled actuators, which allows the continuous acquisition of results. We used a load cell with a capacity of 50 kN for both actuators. Figure 10 shows the test setup and the instrumentation used.

Figure 10: *Test setup and instrumentation used*

Analysing the results obtained during the application of the vertical compression (Figures 11), a quite homogeneity is observed. The stiffness remains constant along the two different vertical compression values, and the maximum displacement increases with that value, as expected.

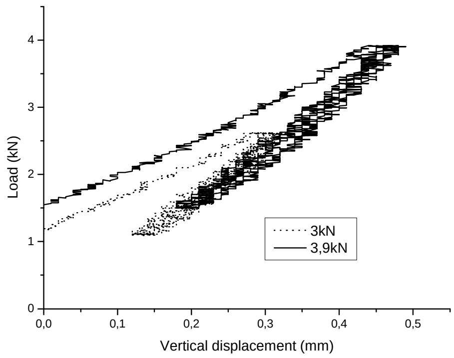


Figure 11: *Load-vertical displacement*

After, and keeping constant the value of the vertical compression wanted, a horizontal displacement of the middle log was applied. The experimental load-slip curves obtained are very similar with differences only in the load value after which the slip began. After that load value, the load slightly decreases until its stabilization.

This behaviour is explained by the difference between the coefficient of static friction and coefficient of kinematic friction (Figure 12).

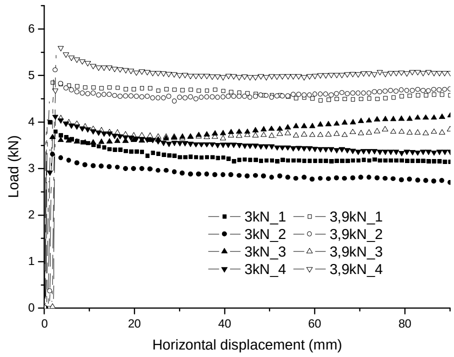


Figure 12: *Load-horizontal displacement*

The specimen with a vertical compression of 3 kN presented an average value of the maximum load equal to 4 kN (CoV=8,4%) while 5 kN (CoV=12,8%) was registered under 3,9 kN of vertical compression. In terms of coefficient of static friction, 1,33 (CoV=8,4%) and 1,28 (CoV=12,8%) were measured whereas 1,11 (CoV=15,5%) and 1,49 (CoV=11,8) have been obtained for the kinematic friction coefficient, under a vertical compression of 3 kN and 3,9 kN, respectively.

In the second step of the experimental campaign, 8 cyclic tests, divided in 4 groups, were performed on full-scale walls made of 5 logs (75 cm height). Each group composed by 2 walls, was tested under different values for the vertical pre-compression (10 kN, 30 kN, 50 kN and 70 kN) while a quasi static cyclic horizontal displacement (Figure 13) was implemented in the top of the wall, in accordance with the recommendations of EN 12512:2001 [11].

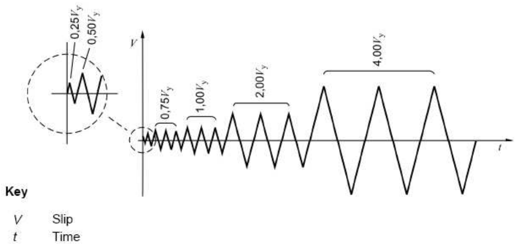


Figure 13: *Loading procedure adopted for the cyclic tests*

The test setup and the instrumentation used are similar to the ones used to evaluate the in-plane behaviour of full-scale log walls that will be presented in the next section of this paper. The unique difference is that the walls used here do not have interceptions with orthogonal walls, being simply made of 5 overlapped logs.

A summary of the tests results is presented in Table 9, namely, in terms of maximum load values in compression (F_{max}^-) and tension (F_{max}^+) and the equivalent viscous damping ratio (ν_{eq}).

Table 9: *Main results obtained from the cyclic tests on 5 overlapped logs*

Test	Pre-comp (kN)	F_{max}^- (kN)	F_{max}^+ (kN)	ν_{eq}
L1	10	-5,51	5,54	0,506
L2		-4,87	5,47	0,522
L3	30	-12,86	11,68	0,442
L4		-11,41	11,59	0,509
L5	50	-18,71	17,37	0,471
L6		-18,25	17,35	0,490
L7	70	-25,95	25,7	0,493
L8		-23,67	26,18	0,481

The results obtained demonstrate the symmetric response of the walls and the very high values of the equivalent viscous damping ratio that can be achieved. However, it is important to notice that the huge dissipation of energy is due to larges displacements and based on friction resistance mechanisms. Results obtained for the maximum load applied shows a linear correlation ($y = 0.366x$, with a R^2 of 0,98) with the vertical compression value.

5 IN-PLANE BEHAVIOR OF LOG WALLS

The main objective of this work is to evaluate the in-plane behaviour of timber log walls subjected to lateral (horizontal) actions. To achieve that, and as conclusion of the several precedent numeric and experimental studies already presented, an experimental campaign composed by full-scale log walls was performed. Two distinct transversal stiffness (wall type 1 and 2), two vertical pre-compression values (10,1 kN and 48 kN) and the influence of the slenderness of the wall (6,25 and 11,25) have been study. For each possible combination of the variables under study, one monotonic and two cyclic loading tests were performed. In the total 13 walls were tested, 4 under monotonic loading and 9 under quasi-static cyclic (Table 10).

Table 10: *Tests performed on full-scale timber log walls*

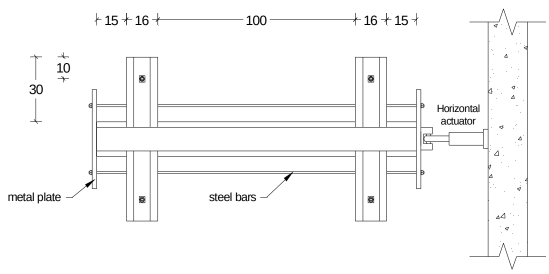
Test number	Loading	Wall type	Heigh (cm)	Pre-comp (kN)
W1_1	monotonic	1	75	10,1
W1_2	cyclic			
W1_3				
W1_4	monotonic			48
W1_5	cyclic			
W1_6				
W2_1	monotonic	2	75	10,1
W2_2	cyclic			
W2_3				
W2_4	monotonic			48
W2_5	cyclic			
W2_6				
W2_7	cyclic	2	135	48

Monotonic tests aimed at analysis of the failure modes and at defining the limits of the elastic displacement, needed to define the cyclic procedure according to EN 12512:2001 [11]. Cyclic tests permit the quantification of resistance and its reduction after several cycles. In addition they allow assessing the capacity to dissipate energy and to have a quantification of the ductility.

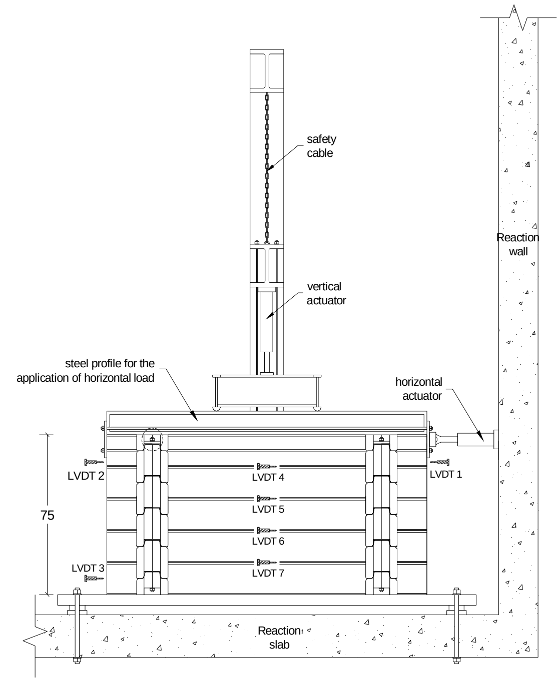
In the first test carried out (W1_1), monotonic loading of a wall type 1 under a vertical compression of 10,1 kN, a displacement of 50 mm at the top of the wall was applied with a constant movement of the hydraulic head of 0,03 mm/s. In the next tests, and because in those conditions testes take too much time, it was decided to apply 100 mm displacement on top of the wall through a constant rate of 0,06 mm/s.

All tests performed, monotonic and cyclic, are composed by a preliminary step aimed at ensure the adequate contact between logs and to remove eventual voids. This step consist in the application of the vertical compression level in 3 minutes (56,1 N/s and 266,67 N/s), keeping then the load value for 3 minutes after which the wall was unload within 3 minutes. This process was repeated 4 times for each wall. Total vertical displacement of the wall and relative vertical displacement between logs were recorded during this preliminary step for further analysis. After that, the vertical compression level was apply in 3 minutes and then kept constant during the implementation of the horizontal displacement history on the top of the wall. This horizontal displacement history was defined according to [11] using the elastic limit displacement obtained in the corresponding monotonic test, performed previously.

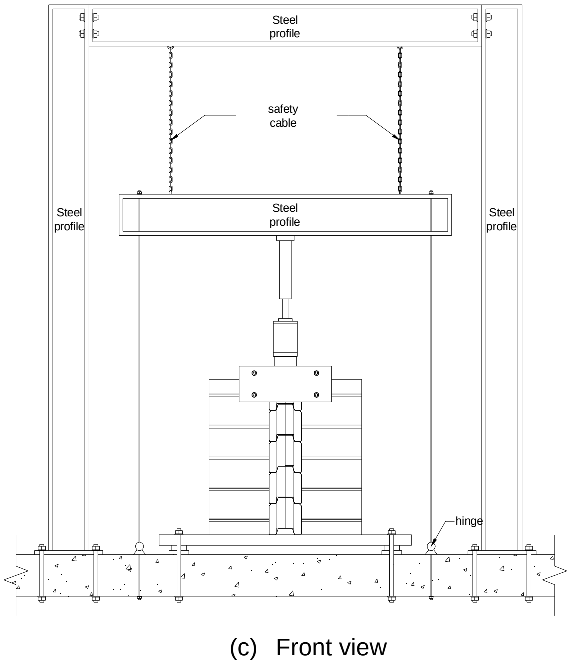
Figure 14 shows the test setup and instrumentation adopted in the case of the walls with 75 cm height. Seven displacement transducers were used to measure: the horizontal slip between each log (4), the horizontal displacement on the top (1) and bottom (1) in the front of the wall and the horizontal displacement on the top of the back of the wall, near the hydraulic jack in charge to implement the displacement history.



(a) Plan view



(b) Lateral view



(c) Front view

Figure 14: *Test setup and instrumentation adopted on the full-scale timber logs walls tests*

In the case of the 135 cm height wall test, a different configuration of the transducers responsible to register the horizontal slip between logs had to be change (Figure 15).

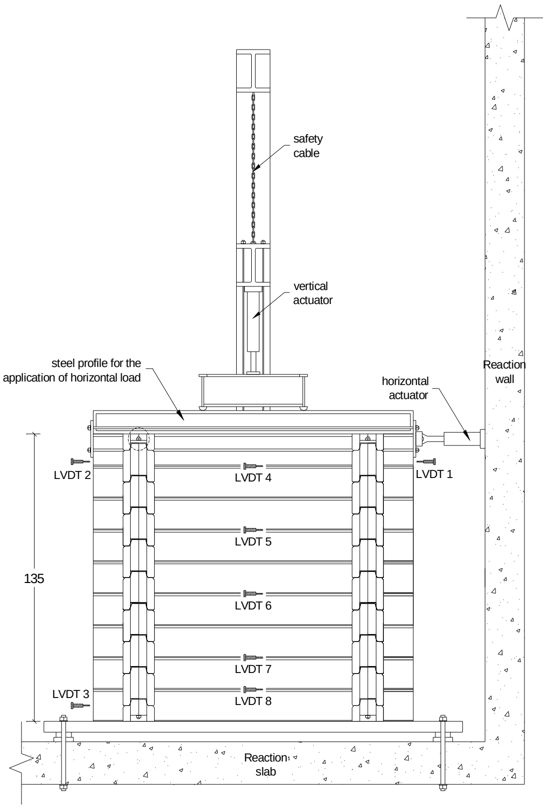


Figure 15: *Instrumentation scheme adopted in the case of the 135 cm height wall*

5.1 ANALYSIS OF RESULTS

The results obtained in the monotonic tests (Figure 16), shows that there is no difference between wall type 1 (Test W1_1 and Test W1_4) and wall type 2 (Test W2_1 and Test W2_4). In other words, the fact that the wall is fixed to the foundation through an angle connector (BMF 40314) or not, has little influence on the global behaviour of the wall. The difference between wall type 1 and wall type 2 is that in the first angle connectors have been used do fixed the first log to the foundation. Wall type 2 did not have this connection, but the two short orthogonal wall used to simulated connection between exterior log walls, were fixed to the steel frame located in the base of the specimen (log wall).

Experimental results show that the behaviour of the walls tested depends on the level of vertical compression and the transversal stiffness materialized by the orthogonal walls.

For the same transversal stiffness the response is similar. Increasing the level of vertical pre-compression, both stiffness and load increases, although the maximum force is fairly constant (64,03 kN, 60,2 kN and 63,18 kN). The value recorded in the first test (33,29 kN) should not be considered in this analysis because corresponds to a displacement in the top of the wall of 50 mm only.

The same conclusions cannot be extended to the results obtained in cyclic tests. The walls of type 2, with orthogonal short walls fixed to the foundation, showed a better performance under cyclic horizontal displacement. In both cases, walls types 1 and 2, the value of pre-compression is reflected in the resistance to lateral wall (Figures 17, 18, 19 and 20).

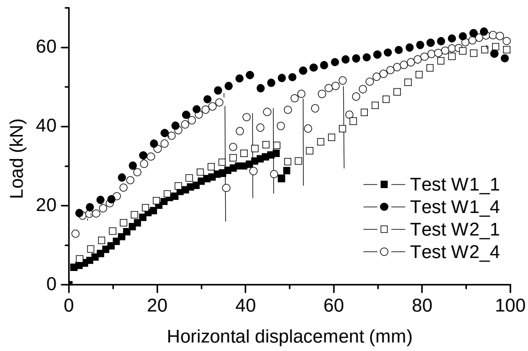


Figure 16: *Load-displacement curves at the top of the wall obtained in the monotonic tests*

The force-displacement response obtained on the cyclic tests follows the behaviour registered under the monotonic loading. In the tests on fixed walls to the foundation through the first log (type 1), maximum loads values of F_{max}^{+}=24,49 kN and F_{max}^{-}=-31,81 kN were obtained for a vertical pre-compression of 10,1 kN, and F_{max}^{+}=44,67 kN and F_{max}^{-}=-48,83 kN were registered for a vertical pre-compression of 48 kN. In the case of the walls type 2, maximum forces values of F_{max}^{+}=28,82 kN and F_{max}^{-}=-42,81 kN were measured for a vertical pre-compression of 10,1 kN and F_{max}^{+}=50,84 kN and F_{max}^{-}=-54,72 kN were obtained for a vertical pre-compression of 48 kN.

The experimental force-displacement curves obtained in the cyclic tests demonstrates the capacity of the timber logs walls to dissipate energy in both directions.

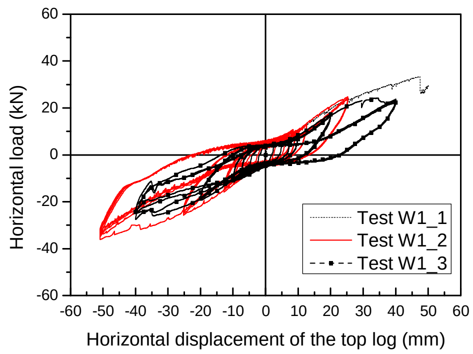


Figure 17: *Load-displacement curves obtained from walls type 1 and vertical pre-compression of 10,1 kN*

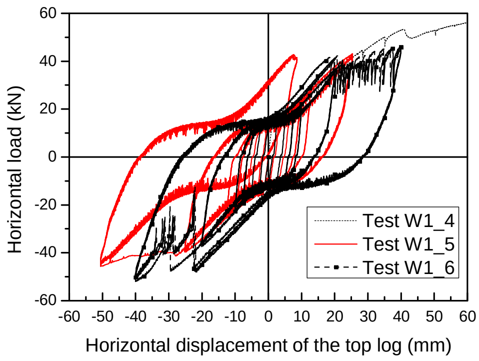


Figure 18: *Load-displacement curves obtained from walls type 1 and vertical pre-compression of 48 kN*

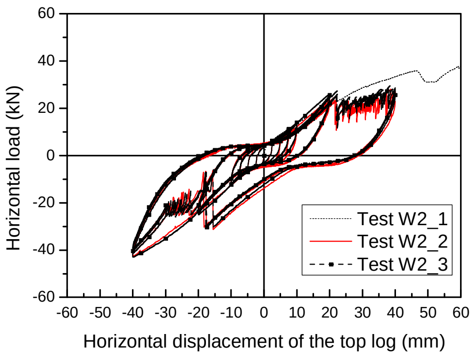


Figure 19: *Load-displacement curves obtained from walls type 2 and vertical pre-compression of 10,1 kN*

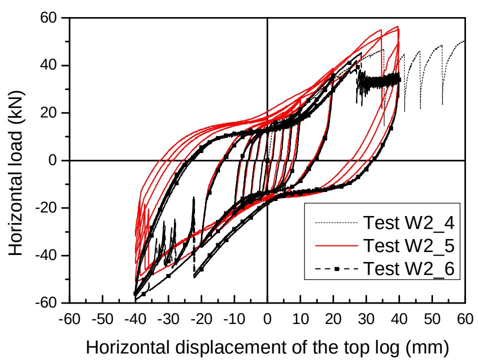


Figure 20: *Load-displacement curves obtained from walls type 2 and vertical pre-compression of 48 kN*

Increasing the slenderness of the timber log walls, from 6,25 to 11,25 (W2_7), results in a significant reduction of the wall lateral resistance, Figure 21. In this last test the maximum force values recorded were F_{max}^{+}=19,63 kN and F_{max}^{-}=-21,69 kN while the similar wall with a slenderness of 6,25 presented F_{max}^{+}=44,67 kN and F_{max}^{-}=-48,83 kN.
Nevertheless, experimental results obtained indicate a good dissipative behaviour of the slenderer wall, characterized by force-displacement curves symmetrical and quite large.

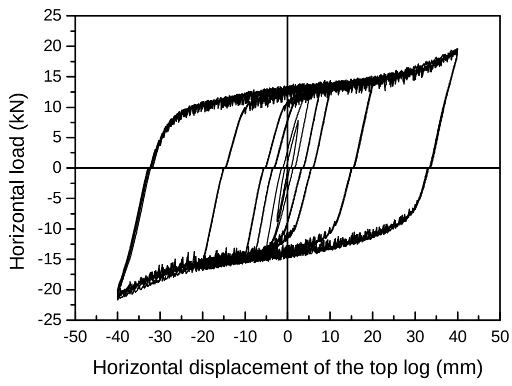


Figure 21: *Load-displacement curve at the top of the wall of 135 cm (Test W2_7)*

Based on the experimental results obtained on the cyclic tests, and following EN 12512:2001 [11], equivalent viscous damping ratio by hysteresis (ν_{eq}) was calculated, Table 11.

Table 11: *equivalent viscous damping ratio*

Test	Wall type	Pre-comp (kN)	Heigh (cm)	ν_{eq}
W1_2	1	10,1	75	0,093
W1_3				0,103
W1_5		48		0,158
W1_6				0,219
W2_2	2	10,1		0,135
W2_3				0,138
W2_5		48		0,237
W2_6				0,187
W2_7			135	0,341

Comparing the experimental (ν_{eq}) obtained it is possible to conclude that wall type 2 dissipates more energy that wall type 1. Moreover, this dissipation increases with the vertical pre-compression and with the slenderness of the wall.
In terms of failure mode, no significant difference exists between both wall types either the value of the vertical pre-compression and the slenderness seems to have not influence. Analysing in detail the horizontal slip between the logs measured during all tests performed, it is obvious a linear variation on that value with the height of the logs.

6 CONCLUSIONS

Despite being a traditional system used on timber constructions, Rusticasa produces one construction system based on timber log that, in result of certain particularities, make necessary a series of experimental and numeric studies to apply to European Technical Approval (ETAG-012 [3]).
In this work, the main resistant mechanism of the timber log walls were analyzed, in particular, the ones concerned with the in-plane resistance to horizontal loading. Timber logs used to make the walls were

characterized and both connections between logs and between walls were studied trough numerical and experimental studies. Considerable friction stresses are developed on the connection between logs, which are, as expected, function of the vertical pre-compression level.

Special attention was paid to the connection of the walls with the foundation because the way as it is made by Rusticasa, is unusual. This connection was tested and its influence on the global behaviour of walls subjected to in-plane displacement was assessed.

The connection between orthogonal walls, namely, the interlock between the logs of exterior walls is the main resistant mechanism of timber log walls under in-plane horizontal loads. Inside the halved joint used to materialize this intersection, shear stresses and compression stresses perpendicular and parallel to the grain occur. In the tests performed on full-scale walls, the localized failure was obtained always by compression perpendicular to the grain. Those tests, aimed at evaluate full-scale timber log walls under different vertical pre-compression levels, distinct connection between the first log and the foundation, two types of stiffness of the orthogonal walls and to assess the effect of the slenderness of the wall.

The experimental results obtained show a good capacity of these walls to dissipate energy, without any impairment of strength being the monotonic response normally envelope to the behaviour obtained on the cyclic tests. The connection between the first log and the foundation, for the wall geometry evaluated, is not important to the global behaviour, which is function of: a) the stiffness of the orthogonal walls; b) vertical pre-compression value; and, c) wall slenderness.

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REFERENCES

[1] Hirai, T., Kimura, T. Yanaga, K. Sasaki, Y. Koizumi, A.: *Lateral resistances of log constructions*. Proceedings of the World Conference on Timber Engineering, 2004, Volume I.

[2] National institute for land and infrastructure management et al.: *Technical standard and design examples for log constructions*, Kogaku Tosho, 2003.

[3] ETAG 012, *Log Building Kits*. Guideline for European Technical Approval, European Organization for Technical Approvals, June, 2002.

[4] EN 386:2001. *Glued laminated timber - Performance requirements and minimum production requirements*. CEN, 2001.

[5] Anon, *Nordic Timber - Grading rules for pine and spruce sawn timber* (The Blue Book). Stockholm: The Assoc. of Swedish Sawmillmen. ISBN 91-7322-227-5, 1994.

[6] NP EN 1194:1999. Estruturas de Madeira. Madeira lamelada-colada – Classes de resistência e determinação dos valores característicos. IPQ, Lisbon, 1999.

[7] EN 408:2003. *Timber structures – Structural timber and glued laminated timber – Determination of some physical and mechanical properties*. CEN, 2003.

[8] Branco, J.M. and Cruz, P.J.S.: *Caracterização Mecânica de Toros de Madeira Lamelada Colada*. 7º Congresso Nacional de Mecânica Experimental, UTAD, 23-25 Janeiro, 2008. (in Portuguese).

[9] Leichti, R. J., R. J. Scott and T. H. Miller. An experimental investigation of foundation anchorage details and base shear capacity for log buildings. *Forest Products Journal*, Vol. 55, No. 4, 2001.

[10] EN 1995-1-1:2004. *Eurocode 5: Design of timber structures - Part 1-1: General - Common rules and rules for buildings.* CEN, Brussels, 2004.

[11] EN 12512: 2001. *Timber structures - Test methods - Cyclic testing of joints made with mechanical fasteners*. CEN, 2001.

[12] EN 26891:1991. *Timber structures. Joints made with mechanical fasteners. General principles for the determination of strength and deformation characteristics*. CEN, Brussels, 1991.